Mirosław Czechowski
Gdynia Maritime University, Faculty of Marine Engineering, Poland

CORROSION FATIGUE OF GMA WELDED Al–Mg ALLOY

ABSTRACT

This article presents the results of the low-cycle fatigue tests of AW-5059 Alustar alloy. Gas metallic welding in argon arc shield was used. The low-cycle fatigue tests were carried out in the air and 3.5% water solution NaCl, with stable amplitude of the stress value. The stresses were changed in the symmetric cycle (the stress ratio was R = -1) with constant strain rate of 5 mm/min and the frequencies oscillating between 0,08÷0,2 Hz. During the tests the following was observed: number of cycles until the specimen's destruction, upper and lower extreme values of force and strain for the selected cycles, duration time of the test and frequency. In case of the specimens exposed in 3,5% water solution NaCl the fatigue durability is lower than the durability of the specimens tested in the air. The article depicts the changes in the total strain amplitude ε_{ac} [mm] depending on the number of cycles [N] obtained in the tests with σ_a = const and the low-cycle fatigue resistance for the welded Alustar alloy.

Key words: *Corrosion fatigue; Al-Mg alloy.*

INTRODUCTION

The argon arc shielded GTA welding and GMA welding are most frequently used methods of welding Al-Mg alloys. The susceptibility of Al-Mg alloys to hot cracking when welding decreases when the content of Mg > 2% increases [1]. The joints of the welded reinforced Al-Mg alloys have got non-homogenous mechanical properties. The bigger their heterogeneity is, the bigger is the degree of cold work [1]. The joint has got worse mechanical properties since in result of the welding process it obtains the coarse-grained structure. In the heat affected zone (HAZ) the mechanical properties and hardness are smaller than the properties of the native material reinforced by the cold work. This is the consequence of re-crystallization during the welding process [1].

During exploitation of ship hulls made of Al-Mg alloy, which are subject to dynamic changeable loads, some cracks appeared. The cracking was caused by huge technological stresses as well as considerable changeable exploitation stresses. The stresses' frequency was 0,2 Hz. They occurred in the range of limited fatigue resistance.

The technical literature often describes the results of fatigue tests made with rotary bending and elongation-stress activity, usually with high frequencies oscillating between 30÷40 Hz. [1]. When the frequency of loads increases from 0,2 Hz to 40 Hz, the fatigue resistance distinctly increases, as well [1].

During the low-cycle fatigue tests the applied stress exceeds the yield point what causes substantial deformation of the material. Such deformations or stresses may occur in many industrial appliances under service conditions. For instance such difficult conditions take place during utilizing of airplanes, pressure tanks, turbine parts, pipelines or hulls of sea-going ships.

Aluminum alloys of 5xxx series and their welded joints show good resistance to stress corrosion cracking in sea water [3]. Tests performed in rapid sea water flow have shown better corrosion resistance of Al-Mg alloys welded by the MIG method as compared to joints welded by the TIG method [4].

RESEARCH METHOD

The tests carried out in a symmetric tension-compression cycle (the stress ratio was R = -1) were performed on the testing machine INSTRON 1195 with a corresponding software. Low-cycle fatigue tests were performed on round cross-section specimens of diameter d = 6 mm and gauge length L_0 = 20 mm and cut out perpendicular to the axis of welding. The gauge was situated in the weld zone. The test was carried out with controlled stress (δ_a = const), at a constant strain rate 5 mm/min and frequencies in the 0,08 ÷ 0,2 Hz range. Values of stress amplitude σ_a were selected in dependence on plastic strain set in the, "zero" cycle from the following series: 0,2 mm, 0,4 mm, 0,8 mm, 1,2 mm, 1,6 mm [5, 6]. The following quantities were recorded during the tests: number of cycles to failure, upper and lower boundary values of stress and strain for the selected cycles, time of tests duration and frequency. The tests were performed at constant temperature t = 21ºC in the air and in 3,5% NaCl solution.

In the tests a novel aluminum alloy AW-5059 H321 (Alustar) was used. Chemical composition of the alloy is given in Table 1.

Table 1. *Chemical composition of the AW-5059 H321(Alustar) alloy*

Alloying components content [%] (weight)										
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	B	Zr	Al
0,037	0,092	0,011	0,767	5,411	0,003	0,571	0,025	0,001	0,114	rest

Sheets made of Alustar were welded by GMA (Gas metal-arc), popolary known as MIG welding. Both sides GMA welding was performed with application of AA 5183 alloy as filler material. Sheets of 12 mm thickness were beveled to X by an angle of 110º and 60º before welding.

The mechanical properties of the welded joint obtained in tests on flat specimens (pursuant to PN – EN 895:1995) were as follows: UTS = 296 MPa, YS = 192,7 MPa, El = 7,6% [2].

TESTS RESULTS AND CONCLUSIONS

Example force – strain F = f(ε) diagrams acquired in tests at σ_a = const, are shown in Figs. 1 and 2. The diagrams show the static strain curve A and recorded boundary values of hysteresis loop in selected cycles N.

Amplitude of the total strain ε_{ac}, corresponding to tops of the hysteresis loop changes during tests at σ_a = const, in dependence on the cycle number N. These changes, for the selected representative test samples, are shown in Fig. 3.

Amplitude of the total strain ε_{ac} decreases at first with number of cycles N, until a stable strain (saturation) is reached. So there occurs a cyclic hardening effect [5]. The stable strains are reached after 100 to 150 cycles. After period of cyclic stability there occurs a growth of strain what indicates the initiation and propagation of the crack.

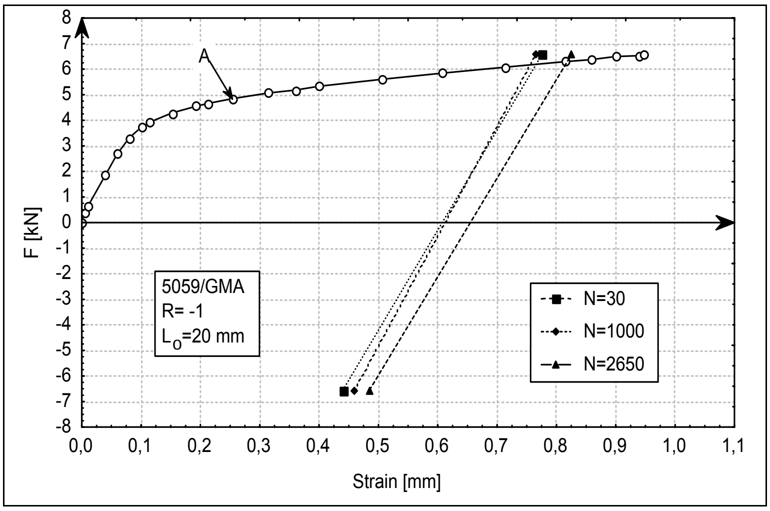

Fig. 1. Boundary points (upper and lower) of hysteresis loop for cycles N = 30, 1000 and 2650 against the background of static force curve A. Tests at σ_a = const. Initial plastic strain ε_p = 0,8 mm

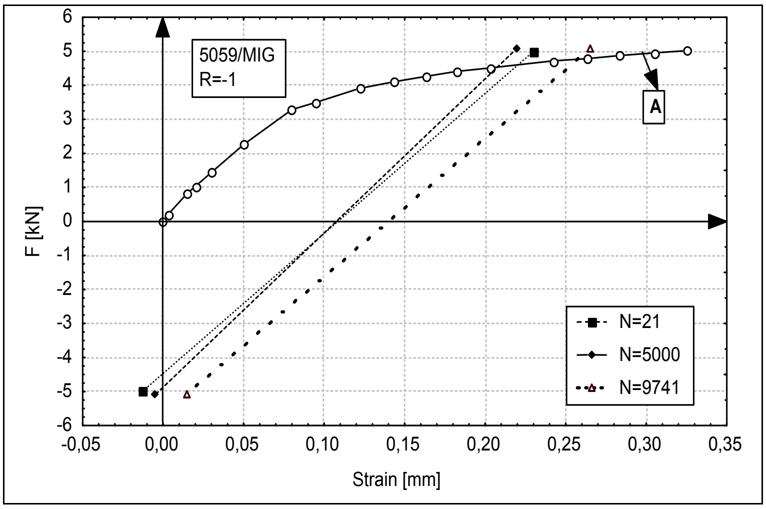

Fig. 2. Boundary points (upper and lower) of hysteresis loop for cycles N = 21, 5000 and 9741 against the background of static force curve A. Tests at σ_a = const. Initial plastic strain ε_p = 0,2 mm

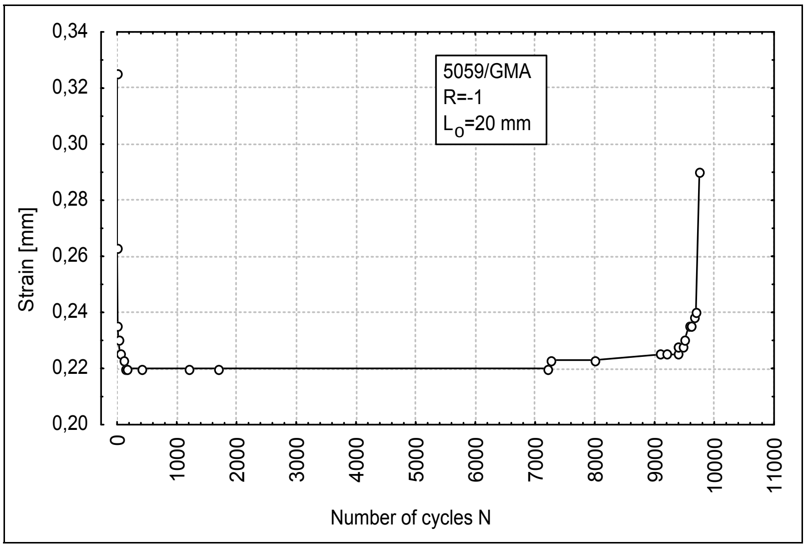

Fig. 3. Change of total strain amplitude ε_{ac} [mm] in dependence on the cycles number N obtained during the tests at σ_a =const (180,5 MPa). Initial total strain ε_c = 0,33 mm. Alustar alloy welded with GMA (MIG) method. Stable strain ε_{as} = 0,22 mm

From the presented diagram (Fig. 3) for different but constant values of cyclic stress σ_a = const different values of stable strain ε_{as} are obtained. These data are used to plot a graph $\sigma_a = f(\varepsilon_{as})$, called the curve of cyclic strain [5, 6]. The cyclic strain curve for the tested alloy, in logarithmic coordinates system, is shown in Fig. 4.

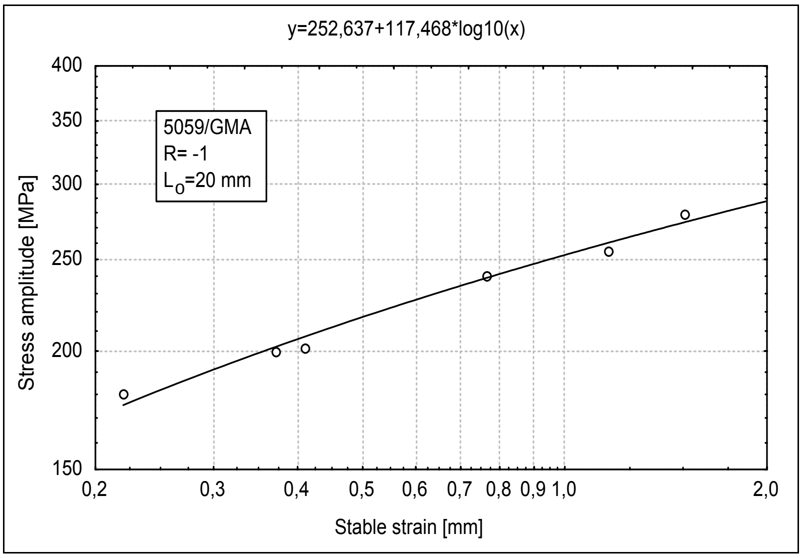

Fig. 4. Diagram of cyclic strain for Alustar alloy welded with GMA method

Diagram of low-cycle fatigue life in the air and in 3,5% NaCl water solution, of the 5059 alloy welded with GMA, determined at a strain rate 5 mm/min, in symmetric tension-compression cycle at σ_a = const, is shown in Fig. 5.

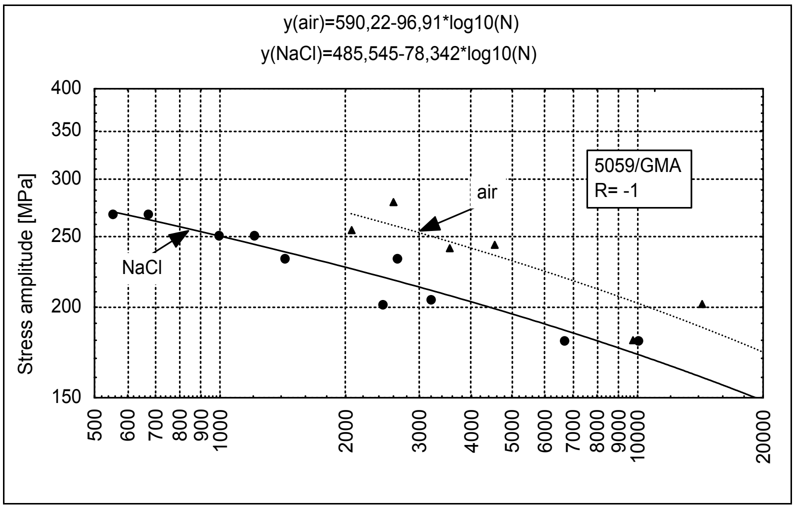

Fig. 5. Low-cycle fatigue properties of GMA-welded Alustar alloy

The time to fracture for test pieces exposed in 3,5% NaCl water solutions is lower than the time to fracture of specimens tested in the air. At greater stresses at 0,93 UTS (R_m) decrease of the time to fracture reaches up to 80%. Samples subjected to cyclic tension-compression in 3,5% NaCl solution, at stresses of 0,61 UTS, showed low-cycle strength lower by abt. 18% than specimens tested in the air at similar stresses. So the degree of the time to fracture decrease for test pieces exposed in 3,5% NaCl solution as compared to the strength of specimens tested in the air depends on the value of plastic strain.

Analysis of fracture surfaces was performed with scanning electron microscope (SEM) Philips XL 30. Typical fracture images obtained after fatigue tests are shown in Figs. 6÷12.

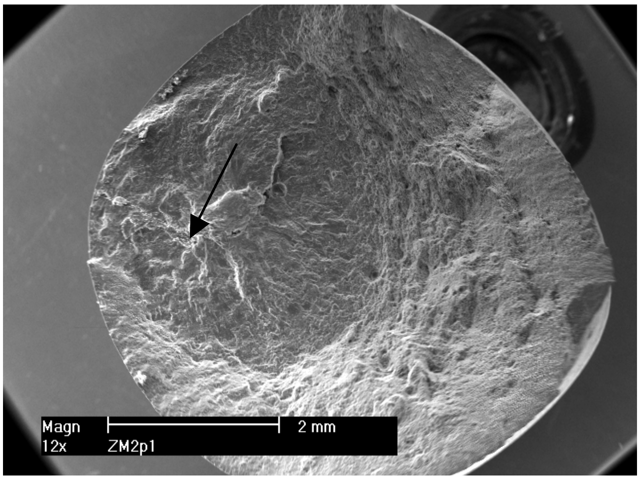

Fig. 6. Fatigue fracture image of test specimen of Alustar alloy welded by GMA. Fatigue zone (marked with an arrow) and plastic fracture zone are visible; sample strained in air

A zone of fatigue fracture with cleavage fracture (Fig. 6, 8, 9, 11) which is passing into a plastic cracking in the place of fracture (Fig. 10, 12) are distinctly visible on the fractures of the examined samples. The cracking started on the surface or inside the joint. The process was initiated in the observed voids which appeared around the particles of inter-metallic phases or in the welding defects inside the material. (Fig. 6, 7, 13). Aggressive chloride medium inside tip significantly accelerates its propagation.

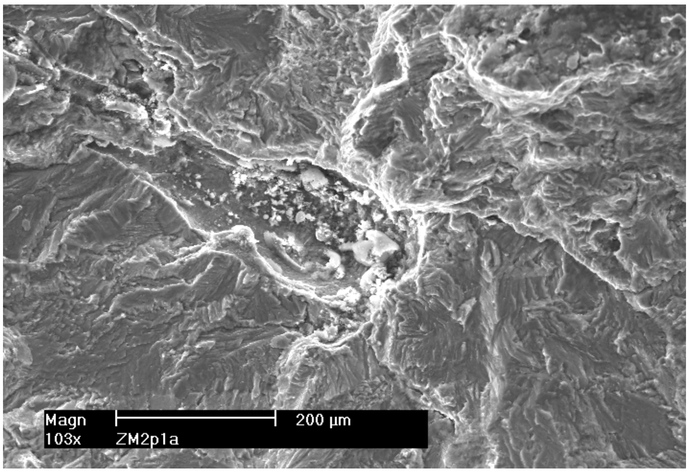

Fig. 7. Part of the fatigue fracture zone from Fig. 6. Region of fatigue crack initiation (welding defect)

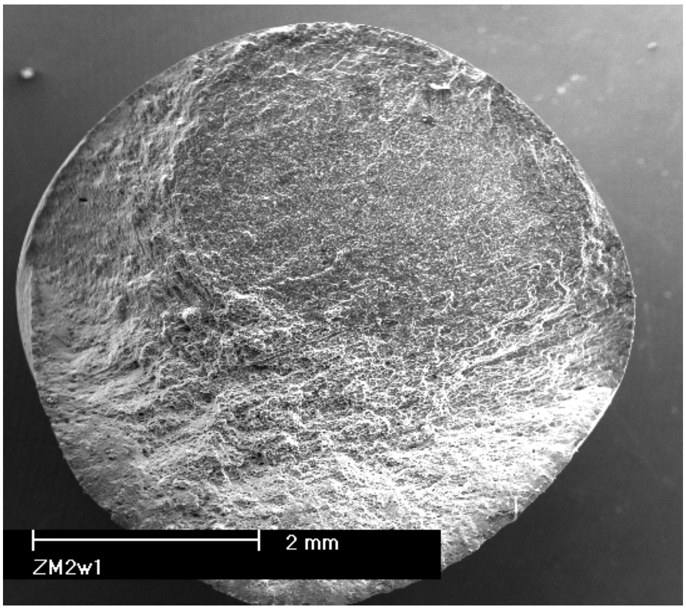

Fig. 8. Fracture surface of Alustar alloy welded with GMA method (sample strained in NaCl)

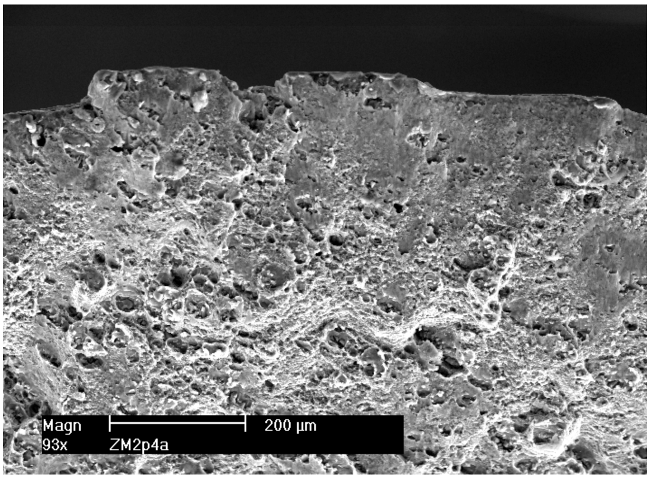

Fig. 9. Fragment of fatigue fracture surface, sample strained in air

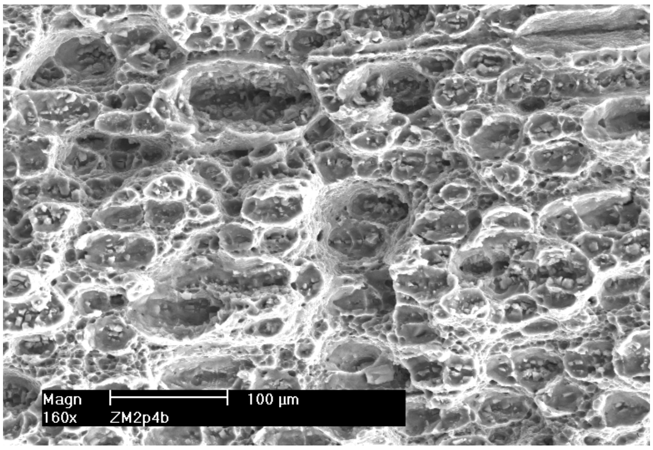

Fig. 10. Plastic fracture zone with visible dimples and cracked inter-metallic phases

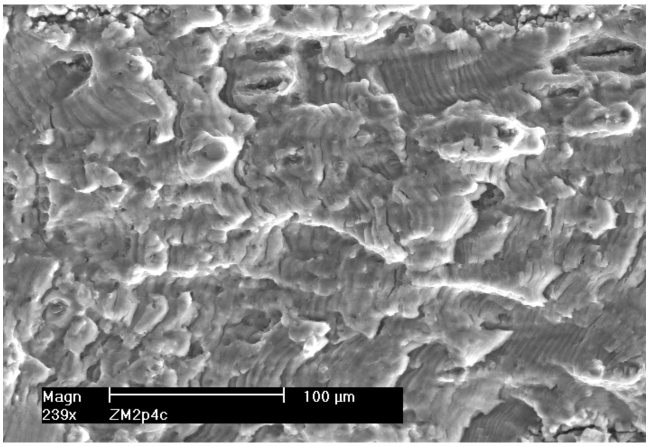

Fig. 11. Part of the fatigue fracture zone from Fig. 9

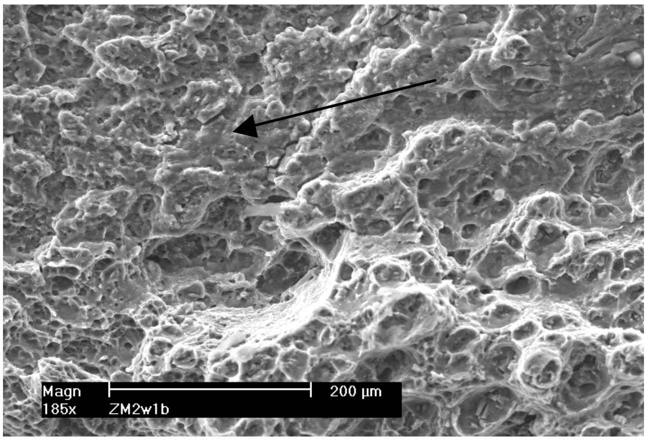

Fig. 12. Fragment of passage from the fatigue fracture (marked with an arrow) into a plastic fracture

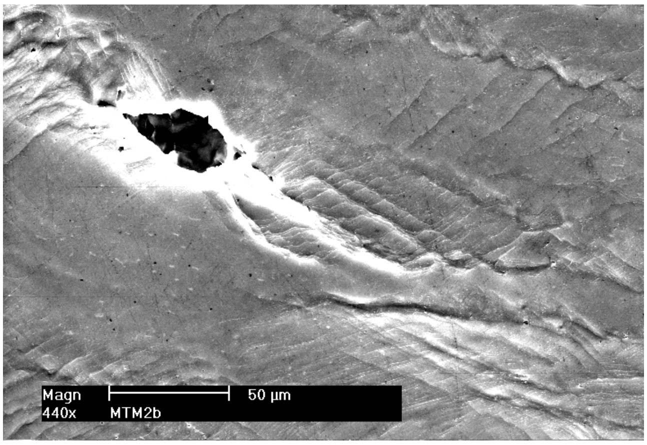

Fig. 13. The crack initiation on the strained surface of the Alustar alloy joint welded with GMA method with visible slip bands (SEM)

CONCLUSIONS

1. During the process of deformation in the symmetric cycle, with δ_a = const., of Alustar alloy welded by GMA method, in the first stage a cyclic hardening effect on the material proceeds. After 100–150 cycles the amplitude of deformation reaches a stable level. In the last stage strain increases and the sample is destroyed.
2. The fatigue life for the joints exposed in 3.5% NaCl is lower than the life of the samples examined in the air. The bigger the difference the bigger the plastic deformations.
3. The cracking initiation on the inter-phase borders or welding defects.

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